

The sum total of processes by which a living organism receives and utilizes raw materials for building its structure and maintaining body functions is called **nutrition**. The chemical substance that works as a raw material for body building and maintaining its functions is termed as **nutrient**. A nutrient can be simple or complex organic molecule, or a mineral ion. The two are respectively called **organic nutrient** and **inorganic nutrient**. CO_2 is an inorganic nutrient for plants. Protein component of our diet is organic nutrient for human beings.

Mineral nutrition is the study of source, mode of absorption, distribution and metabolism of various inorganic substances or minerals by plants for their growth, development, structure, physiology and reproduction. The first study in inorganic or mineral nutrition was carried out by Van Helmont in 1648. He observed that in five years the soil lost 56.7 gm in nourishing a young seedling to form a small tree. However, he did not know the significance of his observation. Glauber and Mayhow (1656) got increased plant growth on the addition of salt peter (KNO_3) to the soil. Woodward (1699) was the first to propose that soil provides mineral ingredients for nourishing plants. De Saussure (1804) concluded that the mineral content of the plant is got from the soil. Liebig (1840) clearly depicted the essentiality of mineral nutrition. He gave the **law of minimum** which states that productivity of a soil depends upon the proportionate amount of deficient mineral. German botanist Julius Sachs (1860) demonstrated for the first time that plants can be reared from seedling state to mature state in nutrient solution even in the absence of soil.

Methods to Study the Mineral Requirements of Plants

Mineral requirements of plants is determined by culture experiment first developed by German botanist Julius von Sachs (1860). The technique is believed to have been initiated by Home (around 1750) and improved by Knop (1865). Culture experiments are hydroponic experiments in which plants are grown from seeds to maturity in a defined nutrient solution in complete absence of soil. The early nutrient solutions were based on mostly macronutrients as micronutrients usually accompanied them as contaminants. As the chemically pure salts became available, the importance of micronutrients became clear. The first complete prescription of all known mineral salts required for preparing culture solution was given by Arnon and Hoagland (1940). Iron is provided alongwith a chelating agent, Na-EDTA. Water used in preparing culture solution is twice distilled in glass containers. Salts are chemically pure. In culture experiments, a solution containing the various mineral elements is prepared. A solution having all the essential elements in proper proportion is called **normal** or balanced **nutrient solution**. The element of which deficiency symptoms are to be studied is made deficient in the solution (Table 12.1). Seedlings are reared either directly in such solutions (**solution** or **water culture**) or in earthen pots having sterilized sand (**sand culture**). For studying the effect of microelements, cotyledons or other organs containing reserve food are removed because they are rich source of microelements. In a typical solution culture technique, nutrient solution is placed in superior glass jars or polythene bottles covered with black paper (to prevent growth of algae and reaction of roots to sunlight). The jars contain split covers or corks with holes for suspending seedling, a funnel for adding

solution and a bent tube for aeration (Fig. 12.1). Regular aeration is required for proper growth and activities of roots. pH of solution is checked from time to time and correction made. Culture experiments are useful in knowing :

1. Essentiality of mineral nutrients.
2. Role of an essential element in body structure and protoplasmic constituents of the plants.
3. Role of an essential element in the physiology of plants.
4. Deficiency symptoms.
5. Toxicity due to excess of an element.
6. Interaction of different elements.
7. Role of a nonessential but functional element.

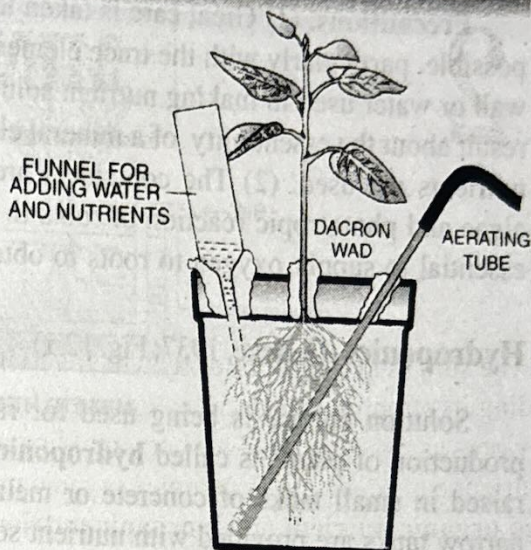


Fig. 12.1. Nutrient solution culture.

Table 12.1 Sach's Formulae for Solution Culture in 1 litre of distilled water (Sachs, 1860)

Constituents	Normal	—P	—Ca	—K	—N	—Mg	—S	—Fe
	gm	gm	gm	gm	gm	gm	gm	gm
KNO ₃	0.70	0.70	0.70	—	—	0.70	0.70	0.70
CaSO ₄ .2H ₂ O	0.25	0.25	—	0.25	0.25	0.25	—	0.25
Ca(H ₂ PO ₄) ₂ .2H ₂ O	0.25	—	—	0.25	0.25	0.25	0.25	0.25
MgSO ₄ .7H ₂ O	0.25	0.25	0.25	0.25	0.25	—	—	0.25
NaCl	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
FeCl ₃ .6H ₂ O	0.005	0.005	0.05	0.005	0.005	0.005	0.005	—
Ca(NO ₃) ₂	—	0.16	—	—	—	—	—	—
K ₂ SO ₄	—	—	0.20	—	—	0.17	—	—
Na ₂ HPO ₄ .12H ₂ O	—	—	0.71	—	—	—	—	—
NaNO ₃	—	—	—	0.59	—	—	—	—
KCl	—	—	—	—	0.52	—	—	—
CaCl ₂	—	—	—	—	—	—	0.16	—
MgCl ₂	—	—	—	—	—	—	0.21	—

Table 12.2 Knop's formula in grams for one litre of normal solution (Knop, 1865)

KNO ₃	—	0.2	KH ₂ PO ₄	—	0.2
Ca(NO ₃) ₂	—	0.8	FePO ₄	—	0.1
MgSO ₄ .7H ₂ O	—	0.2			

Table 12.3. Arnon and Hoagland's (1940) complete nutrient solution

Chemical	gm/litre	Chemical	mg/litre
KNO ₃	1.02	H ₃ BO ₃	2.86
Ca(NO ₃) ₂	0.492	MnCl ₂ .4H ₂ O	1.81
NH ₄ .H ₂ PO ₄	0.23	CuSO ₄ .5H ₂ O	0.08
MgSO ₄ .7H ₂ O	0.49	ZnSO ₄ .7H ₂ O	0.22
		H ₂ MoO ₄ .H ₂ O	0.09
FeSO ₄ .7H ₂ O(0.5%)	and	Tartaric Acid (0.4%)	0.6

Precautions. (1) Great care is taken to avoid contamination of the nutrient solution as far as possible, particularly with the trace elements which are often present as impurities in container's wall or water used in making nutrient solution or reagents being used. This does not give correct result about the essentiality of a mineral element. Due to this fact only purified water and mineral nutrients are used. (2) The containers are covered with black paper to prevent the growth of algae and phototropic reaction of roots to sunlight. (3) Adequate aeration of nutrient solution is essential to supply oxygen to roots to obtain optimum root growth and mineral uptake.

Hydroponics (Gericke, 1937; Fig. 12.1)

Solution culture is being used for raising flowers and vegetables at home. This soilless production of plants is called **hydroponics** (Gk. *hydor*— water, *ponas*— excretion). Plants are raised in small tanks of concrete or metal. The upper covering has supports for plants. The narrow tanks are provided with nutrient solution. A pump circulates air as well as nutrient solution. Roots of the plants are, therefore, regularly provided with aerated nutrient solution. Hydroponics is useful in areas having thin, infertile and dry soils. They conserve water. Additionally hydroponics can regulate pH optimum for a particular crop, control soil borne pathogens, avoid problems of weeding and obtain consistently better yield. Out of season vegetables (e.g., Tomato, seedless Cucumber, Lettuce) and flowers can also be obtained. However, the cost of setting up a hydroponic system is very high.

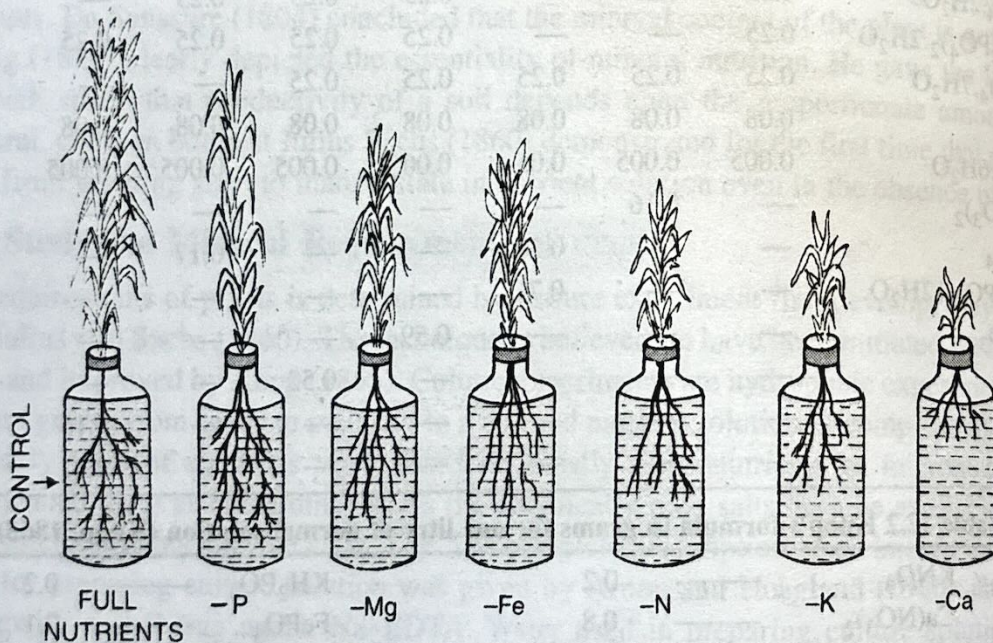
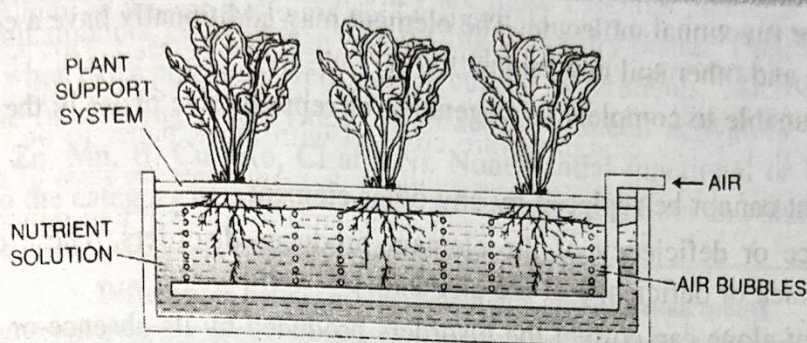
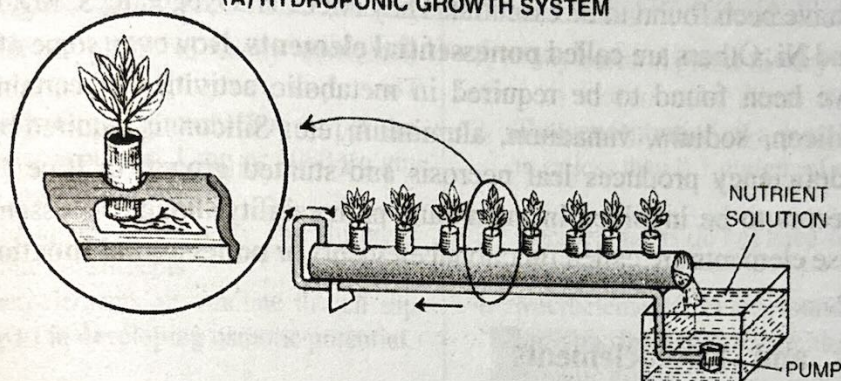


Fig. 12.2. Solution culture technique to know the essentiality of minerals.

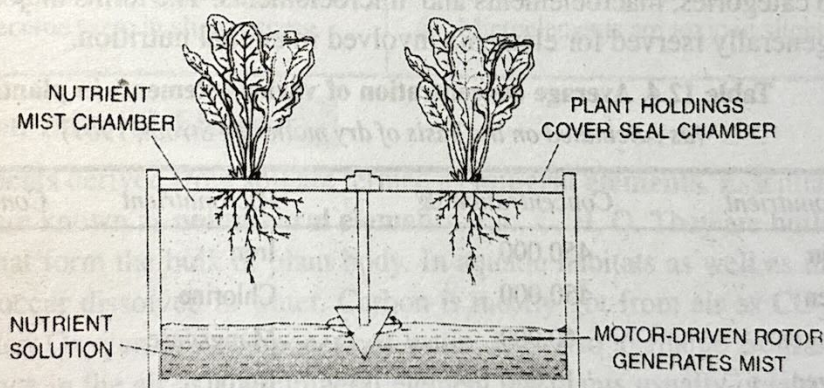
Hydroponics are of three types— tank system, a film system and aeroponics. In tank system hydroponics (Gericke, 1937), the roots are immersed in nutrient solution and air is bubbled through the solution (Fig. 12.3 A). In film technique of hydroponics (Cooper, 1979), plants are grown in a trough or tube having a thin film of recirculated nutrient solution (Fig. 12.3 B). In aeroponics (Weathers and Zobel, 1992) roots are suspended in the air over the nutrient solution which is whipped into a nutrient mist (cloud of moisture in the air) by a motor driven rotor (Fig. 12.3 C).



(A) HYDROPONIC GROWTH SYSTEM



(B) NUTRIENT FILM GROWTH SYSTEM



(C) AEROPONIC GROWTH SYSTEM

Fig. 12.3. Hydroponic and aeroponic systems for growing plants in nutrient solutions under controlled conditions.

Essential Mineral Elements

Most of the minerals present in the soil can enter plants. With the help of sensitive techniques, concentration as low as 10^{-8} g/ml can be detected. More than sixty minerals present in soil have been recorded in plants. Some plants accumulate heavy and toxic materials, e.g., *As-tragalus* (selenium), *Phacelia sericea* (gold), plants growing near nuclear sites (radioactive strontium). All the elements found in plants are not essential for plants. Similarly, all elements essential for animal growth are not required by plants. The most important of them are iodine and sodium. An **essential element** is the one which has a specific structural or physiological role and without which plants cannot complete their life cycle.

Criteria to know essentiality of an element. Arnon and Stout (1939) proposed **criteria** for knowing the essentiality of an element. They are :

1. It is indispensable for the growth of plants.

2. The element is directly involved in the metabolism of plants. It becomes a component of either a structural or functional molecule. The element may additionally have a corrective effect on mineral balance and other soil conditions.

3. A plant is unable to complete its vegetative or reproductive phase in the absence of the element.

4. The element cannot be replaced by any other element.

5. The absence or deficiency of the element produces disorders. These disorders are a direct result of the lack or deficiency of the element.

6. The element alone can correct the disorders produced by its absence or deficiency.

17 elements have been found to be essential. They are C, H, O, N, P, K, S, Mg, Ca, Fe, B, Mn, Cu, Zn, Mo, Cl and Ni. Others are called **nonessential elements**. However, some of the nonessential elements have been found to be required in metabolic activities of certain plants. They include cobalt, silicon, sodium, vanadium, aluminium, etc. Silicon is required by most grasses and cereals. Its deficiency produces leaf necrosis and stunted growth in Rice (Yoshida *et al*, 1959). Sodium seems to be involved in membrane permeability though its essentiality has not been proved. These elements are called functional elements or **nonessential functional** or **beneficial elements**.

Macroelements and Microelements

Essential elements occur in different proportions (Table 12.1) in the plants. They are differentiated into two categories, macroelements and microelements. The terms major, minor and trace elements are generally reserved for elements involved in animal nutrition.

Table 12.4. Average concentration of various elements in plants
(as calculated on the basis of dry matter by Strout, 1961)

Macronutrient	Concentration μg	Micronutrient	Concentration μg
Carbon	450,000	Iron	100
Oxygen	450,000	Chlorine	100
Hydrogen	60,000	Manganese	50
Nitrogen	15,000	Boron	20
Potassium	10,000	Zinc	20
Calcium	5,000	Copper	6
Phosphorus	2,060	Nickel	3
Magnesium	2,000	Molybdenum	0.1
Sulphur	1,000		

(i) **Macroelements** (Macronutrients). They are those essential elements which are present in easily detectable quantities, 1–10 mg per gram of dry matter. Macroelements are usually involved in the synthesis of organic molecules and development of osmotic potential. They are nine in number— C, H, O, N, P, K, S, Mg and Ca. 96% of the dry matter is formed of carbon, hydrogen and oxygen. On **fresh weight basis**, oxygen is the most abundant element in plant body as well as other organisms. On **dry weight basis**, it is almost as abundant as carbon. Of the nonessential functional or beneficial elements, silicon and sodium often occur in the range of macroelements.

Iron occurs in the concentration of less than 1 mg/gm. However, its essentiality was discovered along with other macroelements long before microelements were found to be required. Therefore, it is often regarded to be macroelement.

(ii) **Microelements** (Micronutrients). They are those essential elements which are required by plants in small amounts, equal or less than 0.1 mg/gm of dry matter. Their essentiality came to be known only when extra pure salts were used in culture experiments. Microelements are mostly involved in the functioning of enzymes, as cofactors or metal activators. They are eight in number — Fe, Zn, Mn, B, Cu, Mo, Cl and Ni. Nonessential functional or beneficial elements which belong to the category of microelements are cobalt, vanadium and aluminium.

Differences between Macroelements and Microelements	
Macroelements (Macronutrients)	Microelements (Micronutrients)
1. They occur in plants in easily detectable quantities.	1. They occur in plants in very small amounts.
2. The concentration of a macroelement per gm of dry matter is at least 1 mg or 1000 µg/gm of the dry matter.	2. The concentration of a microelement is equal to or less than 0.1 mg/gm of dry matter.
3. They build up the plant body and different protoplasmic constituents.	3. Microelements do not have such a role.
4. Some macroelements accumulate in cell sap and take part in developing osmotic potential.	4. Microelements, being found in traces only, have no significant role in the development of osmotic potential.
5. Turgor movements are mostly caused by influx & efflux of potassium, a macro-element.	5. None of the microelements have any such function.
6. They do not become toxic in slight excess.	6. Microelements are toxic in slight excess.

Mineral and Non-mineral Elements

Essential elements derived from soil are termed as **mineral elements**. Essential elements got from air or water are known as **nonmineral elements**, e.g., C, H, O. They are building blocks of macromolecules that form the bulk of plant body. In aquatic habitats as well as in soil solution, mineral elements occur dissolved in water. Carbon is mostly got from air as CO₂. Hydrogen is obtained from water. Oxygen is a component of water. It is also available from air. Nitrogen is present in abundance in the air as a nonmineral element but plants usually obtain it from soil as nitrate or ammonium ion. The two are formed by the process of fixation of atmospheric nitrogen though a small quantity can also come from weathering of rocks. Chlorine is got as a mineral from soil but can also be obtained from the atmosphere. Similarly, some sulphur is also absorbed from the atmosphere where it is present as a pollutant in the gaseous state of sulphur dioxide.

Mineral Elements. P, K, S, Mg, Ca, Fe, Zn, Mn, B, Cu, Mo, Cl and N.

Non-Mineral Elements. C, O, H and N.

General Role or Functions of Essential Elements

1. **Constituents of Biomolecules.** Carbon and hydrogen are components of all organic substances. Many of them also contain oxygen. Nitrogen is a constituent of all amino acids, proteins, nucleic acid, chlorophyll, auxin, cytokinins and vitamins. Sulphur occurs in two amino acids—methionine and cysteine. They form a number of proteins. Phosphorus is present in nucleotides, higher nucleotides (e.g., ADP, ATP, CDP, CTP), coenzymes like NAD⁺ and NADP⁺, RNA, DNA and phospholipids. Fe is found in cytochromes. Mg is a component of chlorophyll. Ca and Mg produce pectates of middle lamella.

Depending upon the organic compound formed, mineral elements are of two types : (a) **Framework Elements**. They produce cell walls and storage products of plants, i.e., C, H, O. (b) **Proto-**

Role of Essential Elements and Deficiency Symptoms

Element	Obtained as	Region of plant in which required	Constituent of	Major Functions	Deficiency Symptoms
1. Nitrogen	NO_3^- , NH_4^+ rarely NH_2^-	Everywhere but more in meristems	Amino acids, proteins, enzymes, some coenzymes, nucleotides, ATP nucleic acids, vitamins, hormones, cytochromes, chlorophyll.	Cell division, growth, metabolic activities, photosynthesis	Chlorosis starting from older leaves, stunted growth due to decreased protein synthesis, smaller cells and inhibition or slow divisions, premature leaf fall, lateral buds and tillering suppressed, late flowering, purple colouration of stem, petiole and under surface of leaf in some plants, wrinkling of cereal grains, reduced yield.
2. Phosphorus	$\text{H}_2\text{PO}_4^{2-}$, PO_4^{3-}	Meristems, developing fruits and seeds, withdrawn from older tissues. Stored as phytin or phytic acid.	Nucleotides, ATP nucleic acids, nucleoproteins, phospholipids, NAD^+ , NADP^+ and some other coenzymes.	Energy transfer, cell division, membranes, phosphorylation reactions	Stunted growth, leaves dull green or with purple and red spots of anthocyanins, chlorosis (appears late) with necrosis first in older leaves or premature abscission, delayed flowering, premature fall of flower buds, poor vascular tissues and delayed seed germination.
3. Potassium	K^+	Leaves, meristems, buds and root tips.	Not constituent of any organic substance, cofactor or activator of several enzymes, determines osmotic potential	Maintenance of cell turgidity, opening and closing of stomata, balancing other ions, cation-anion balance, increases hardness, essential for photosynthesis, respiration, protein synthesis and synthesis of various other types, membrane permeability.	Mottled interveinal chlorosis appearing first in older leaves, marginal or apical yellowing or scorch and curling, die back, bushy habit, shorter internodes, loss of apical dominance, cereals may show lodging, loss of cambial activity, plastid disintegration and increase in rate of respiration.
4. Calcium	Ca^{2+}	Meristematic and differentiating tissues. Excess in older leaves.	Calcium pectate of middle lamella, activator of enzymes connected with chromosome formation and many aspects of metabolism.	Selective permeability of cell membrane, organisation of mitotic spindle, meristematic activity, metabolism, prevention of mineral and organic acid toxicity, second messenger for some hormonal signals.	Stunted growth, degeneration of meristems, especially root apex, chlorosis, necrosis and curling appearing first in young leaves, premature flower abscission, blossom end rot of Tomato.

Element	Obtained as	Region of plant in which required	Constituent of	Major Functions	Deficiency Symptoms
5. Magnesium	Mg ²⁺	Leaves, growing areas of root and stem, seeds, withdrawn from ageing leaves.	Chlorophyll, magnesium pectate, activator of enzymes connected with phosphate transfer in respiration, photosynthesis, DNA and RNA synthesis, fat and carbohydrate metabolism, binding of ribosomes.	Formation of chlorophylls, carotenoids and nucleic acids, growth, metabolism and nodule formation in legumes.	Marginal curling, interveinal chlorosis with purple anthocyanin pigmentation appearing first in older leaves, veins green, chlorotic areas may turn necrotic, premature leaf abscission, reduced growth, underdeveloped phloem and pith.
6. Sulphur	SO ₄ ²⁻ , also as SO ₂ from air	Young leaves and meristems, withdrawn from senescent organs.	Two amino acids (methionine and cysteine) and hence their proteins, vitamins (thiamine, biotin), CoA, lipoic acid and ferredoxin, also component of allyl oils of Onion, Garlic and Crucifers.	Chlorophyll formation, growth metabolism and nodule formation in legumes.	Similar to those of nitrogen deficiency both being constituents of proteins. Chlorosis more commonly appearing first in young leaves accumulation of anthocyanins, stunted growth, leaf curl, less juice content in Citrus, reduced nodulation in legumes, smaller chlorotic leaves in Tea (tea yellow).
7. Iron (Micro)	Fe ³⁺ (mostly) Fe ²⁺ (mostly acidic soils)	Everywhere, more along veins. Excess stored as ferritin.	Cytochromes, ferredoxin, nitrogenase, activator of catalase and some other enzymes.	Electron transport in photosynthesis and respiration (Fe ²⁺ $\rightleftharpoons$ Fe ³⁺), development of chloroplasts, chlorophyll and other pigments, protein synthesis.	Interveinal chlorosis appearing first in young leaves, veins initially green, necrosis later on, growth reduced.
8. Manganese (Micro)	Mn ²⁺	Leaves and seeds	Activates enzymes of respiration, photosynthesis and nitrogen metabolism performing oxidation, reduction, decarboxylation, component of oxygen evolving complex.	Metabolism and photolytic evolution of oxygen.	Interveinal chlorosis, grey specks and streaks, legume cotyledons with brownish spots (marsh spot disease), stunted growth, flowers often sterile.
9. Molybdenum (Micro)	HMoO ₄ ⁻ MoO ₄ ²⁻	Everywhere, Mo ⁴⁺ more common in roots	Nitrogenase, nitrate reductase, activator of dehydrogenases.	Nitrogen metabolism (nitrogen fixation, nitrate reduction), ascorbic acid synthesis. Oxidation—	Mottled chlorosis with marginal necrosis and infolding, lamina or upper half of lamina falls down (whiptail)

Element	Obtained as	Region of plant in which required	Constituent of	Major Functions	Deficiency Symptoms
10. Boron (Micro)	BO_3^- or $\text{B}_4\text{O}_7^{2-}$	Leaves and seeds	Connection with any enzyme system not known.	reduction reaction. Carbohydrate transport through phloem, uptake and utilization of calcium, pollen germination, root nodulation, synthesis of pectins, proteins and nucleic acids, membrane functions, cell elongation and cell differentiation.	disease), loosening of inflorescence in Cauliflower, slight growth retardation. Death of root and shoot tips, loss of apical dominance, stunted growth, small size of fruits, rosetting of leaves, stem brittle but stout, black necrosis, disintegration of softer parts—top sickness, brown heart (e.g., Turnip), internal cork (e.g., Apple), heart rot of Sugar Beet, browning of Cauliflower, decreased nodulation in legumes.
11. Copper (Micro)	Cu^{2+}	Everywhere	Component or activator of plastocyanin, cytochrome oxidase, RuBP carboxylase and many other enzymes.	Electron transfer ($\text{Cu}^+ \rightleftharpoons \text{Cu}^{2+}$) maintenance of carbohydrate/nitrogen balance, chlorophyll synthesis.	Die back, skin splitting or exanthema, exuding gummy substance, apical necrosis of young leaves extending towards base along the margins, (leaf tip disease = reclamation disease), blackening of Potato tubers.
12. Zinc (Micro)	Zn^{2+}	Everywhere	Component or activator or several enzymes including carbonic anhydrase, dehydrogenases and carboxylases.	IAA, RNA and protein synthesis, evolution and utilization of carbon dioxide	Leaf malformations like little leaf, leaf rosettes, interveinal chlorosis and several types of leaf distortions, white bud, stunted growth.
13. Chlorine (Micro)	Cl^-	Everywhere	Component of oxygen liberation complex of photolysis, amylase, anion-cation balance, osmotic potential along with K^+ , Na^+ .	Photoproduction of oxygen, cell division, normal production of fruits.	Bronze colour in leaves, leaf wilting, chlorosis and necrosis, stunting of roots and swollen root tips, flower abscission, reduced fruiting.
14. Nickel (Micro)	Ni^{2+}	Leaves and root.	Urease, also required for hydrogenase.	Metabolism of urea and ureides.	Leaf tip necrosis.



Fig. 12.4. Potassium deficiency symptoms in Tomato leaf.



Fig. 12.5. Sugar Beet leaves showing calcium deficiency.

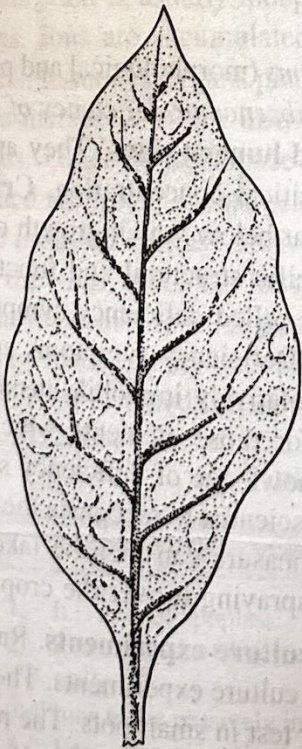


Fig. 12.6. Manganese deficiency pattern.

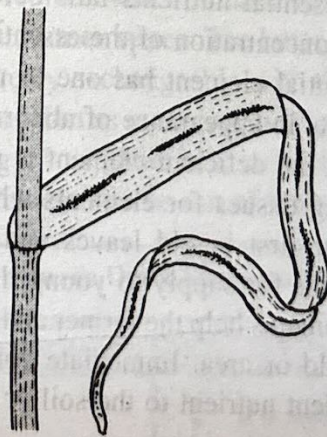


Fig. 12.7. Copper deficiency symptoms in cereal.

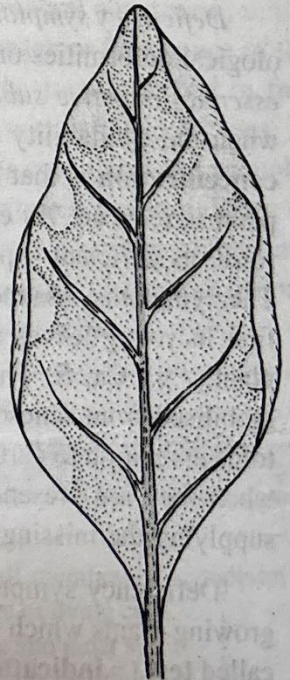


Fig. 12.8. Molybdenum deficiency symptoms.

plasmic Elements. The elements produce protoplasmic constituents like proteins, nucleic acids, chlorophylls, cytochromes, ferredoxin, i.e., C, H, O, N, S, P, Mg, Fe.

2. **Energy Related Compounds.** Magnesium is a component of chlorophyll that takes part in conversion of light energy into chemical energy. Phosphorus is component of ATP which functions as energy currency of the living systems.

3. **Osmotic Potential.** Most of the osmotic potential of cell sap is due to inorganic salts. Osmotic potential is required for water absorption and maintenance of cell turgidity.

4. **Movements.** Free K^+ takes part in stomatal and other turgor movements.

5. **Buffer Action.** Weak acids and their salts function as a buffer against changes of pH.

6. **Oxidation Reduction System.** Metals with variable valency act as electron carriers, e.g., Iron (Fe^{2+} and Fe^{3+}) and Copper (Cu^+ , Cu^{2+}).

7. **Toxic Effects.** Many elements become toxic in higher concentration than the normal, e.g., Cu, B, Mn, Mo, Zn. Others are toxic even in smaller concentration, e.g., Pb, Ni, Se, Al, Hg.

8. **Balancing Elements.** Ca^{2+} , Mg^{2+} and K^+ minimise the toxic effect of heavy elements.

9. **Permeability.** Sodium, Potassium and some other monovalents increase membrane permeability while Calcium and other divalents decrease the same.

10. **Catalytic Effects.** Many enzymes require mineral elements as cofactors. Mg^{2+} is activator of several enzymes of both respiration (e.g., hexokinase, phosphofructokinase) and photosynthesis (e.g., RuBP carboxylase, PEP carboxylase). Zinc is activator of carbonic anhydrase and alcohol dehydrogenase. Molybdenum is required for functioning of dinitrogenase and nitrate reductase. Mn^{2+} is involved in photolysis of water. K^+ is known to be cofactor of some 40 enzymes.

11. **Phloem Transport.** Boron and Potassium are involved in the translocation of organic substances in the phloem.

Deficiency Symptoms of Essential Elements

Deficiency symptoms are externally visible pathological conditions (morphological and physiological deformities or abnormalities) which are produced due to absence or deficiency of some essential nutritive substance. Deficiency symptoms are also called **hunger signs**. They appear when the availability of the essential nutrients falls below the critical concentration. **Critical concentration** is that limited concentration of the essential element below which growth of the plant is reduced. As each essential element has one or more specific structural and functional roles, its deficient supply results in appearance of abnormal signs called deficiency symptoms. The symptoms disappear when the deficient element is supplied. Deficiency symptoms appear first in young leaves and young tissues for elements which are relatively immobile inside the plant, e.g., Ca, S. They appear first in old leaves and tissues for those elements which are mobilised from senescing regions for supply to young tissues. Knowledge of deficiency symptoms in relation to particular elements help the farmer and the farm scientist to recognise the same when they are present in a field or area. Immediate corrective measure can then be taken by supplying the missing or deficient nutrient to the soil or directly spraying it over the crop.

Deficiency symptoms are first studied by means of **pot** and **culture experiments**. Rapidly growing plants which develop characteristic symptoms are used in culture experiments. They are called **test (= indicator) plants**. They are then grown in soil under test in small pots. The results are compared to know the deficiency elements. Similar tests are performed with selected crops.

Excess of minerals are often toxic. The toxicity is studied first in culture experiments and then field or soil trials.

Common Deficiency Symptoms

(1) **Chlorosis**. Non-development or loss of chlorophyll. N, K, Mg, S, Fe, Mn, Zn, Mo. (2) **Stunted Growth**. N, K, Ca, S, Zn, B, Mo, Cl. (3) **Purple Colouration of Shoot Axis or Leaves**. N, P, Mg, S, Mo. (4) **Necrosis**. Death of tissues. Ca, Mg, Cu, K. (5) **Premature Fall of Leaves and Buds**. P, Mg, Cu. (6) **Inhibition of Cell Division**. N, K, S, Mo. (7) **Wrinkling of Cereal Grains**. N, S, Mo. (8) **Dormancy of Lateral Buds**. N, S, Mo. (9) **Late Flowering**. N, S, Mo. (10) **Die Back**. Killing of shoot apex (stem tip and young leaves). K, Cu. (11) **Wilting**. Loss of turgor. Cl. (12) **Death of Root and Shoot Tips**. B. (13) **Bushy Habit of Shoot**. K. (14) **Scorched Leaf Tips**. K. (15) **Interveinal Chlorosis**. Fe. (16) **Whiptail Disease of Leaves**. Mo.

Toxicity of Micronutrients

In higher doses, micronutrients become toxic. Any tissue concentration which reduces dry weight of tissue by 10% is called **toxic concentration**. Critical toxic concentration is different for different micronutrients as well as different plants. For example, Mn^{2+} is toxic beyond $600 \mu\text{g g}^{-1}$ for Soyabean and beyond $5300 \mu\text{g g}^{-1}$ for Sunflower. Toxic effects may be due to direct excess of the micronutrient or its interference in the absorption and functioning of other nutrients. Manganese toxicity (brown spots surrounded by chlorotic veins) is due to (i) Reduction in uptake of iron and magnesium. (ii) Inhibition of binding of Magnesium to specific enzymes. (iii) Inhibition of Calcium translocation into shoot apex. Therefore, excess of Manganese causes deficiency of Iron, Magnesium and Calcium. The toxicity symptoms of Mn are actually combined deficiency symptoms of Fe, Mg and Ca.

ABSORPTION OF MINERALS

Plants absorb their mineral salt supply from the soil through the roots. The most active areas of the root for mineral absorption are the zones of elongation and root hair. The rate of mineral absorption is usually independent of its concentration in the soil. The minerals are absorbed as ions. Ions are accumulated by the plants against their concentration in the soil. Isolated plant cells, tissues or organs placed in mineral solution, show two phases in mineral absorption; initial and metabolic. In the **initial phase** there is a rapid uptake of ions into **outer** or **free space** of the cells. Outer or free space comprises intercellular spaces and cell walls. Ions absorbed in free space are freely exchangeable, e.g., replacement of unlabelled K^+ ions with labelled K^+ ions. In the **metabolic phase** the ions pass into **inner space**. The latter comprises cytoplasm and vacuole. In the inner space the ions are not freely exchangeable with those of external medium. Entry of ions into outer space is **passive absorption** as no energy is required for it. Absorption of ions into inner space requires metabolic energy. It is, therefore, an **active absorption**. Movement of ions into cells is called **influx** while movement of ions out of the cells is called **efflux**.

Differences between Outer Space and Inner Space

Outer Space	Inner Space
1. It is area of apoplast. 2. It is formed of intercellular spaces and cell walls. 3. Ions move passively into outer space. 4. Ions occur in the outer space in freely exchangeable form.	1. It is area of symplast. 2. It is formed of cell membranes, cytoplasm and other structures of living cells. 3. Ions move actively into inner space. 4. There is no free exchange of ions.

TRANSLOCATION OF SOLUTES

After absorption from the soil by epiblema cells, the mineral salts pass radially inwards into the tracheary elements. With the transport of water the mineral salts also pass upwardly to reach the leaves and other parts. That xylem is the pathway for the transport of mineral salts is based on the following facts:

1. Xylem sap contains mineral salts.
2. Salt uptake increases with the increase in the rate of transpiration and transport of water.
3. Ringing and hollowing experiments which disrupt the continuity of cortex, phloem and pith do not influence the rate of mineral uptake till the roots are metabolically active.
4. **Tracer Technique.** Analysis of bark and wood shows that bark (including phloem) contains more minerals than the wood although phloem is not the pathway of transport of minerals. Therefore, Stout and Hoagland (1939) inserted a paraffin paper between xylem (wood) and phloem (bark) upto a length of 23 cm (Fig. 12.10). Radioactive potassium or phosphorous was added to the rooting medium. The concentration of radioactive mineral was found out at various levels in the stem near and in the area of separation of xylem and phloem (Table 12.5). The data shows that in the stripped area little concentration of mineral occurs in the bark though its amount is quite high in the xylem. Greater amount of mineral in the bark above and below the strip is due to local absorption of mineral from xylem by living cells of bark but there is little translocation through it. The pathway is only xylem.

Through xylem the absorbed minerals are passed into leaves. From leaves the mineral salts reach other parts through phloem.

Table 12.5. Concentration of radioactive K^+ after five hours when xylem and phloem are separated.

		Concentration Bark	ppm Wood
Above Strip	SA	53	47
	S ₆	11.6	119
	S ₅	0.9	122
Stripped Area	S ₄	0.7	112
	S ₃	<0.3	98
	S ₂	>0.3	108
	S ₁	20	113
	SB	84	48
Below strip			

Soil as Reservoir of Essential Elements

Soil provides anchorage, air, water and minerals to the plants growing in it. Soil colloids are particles that retain nutrients for release into the soil solution for uptake by roots. Thus, soil colloids maintain reservoir of soluble nutrients in the soil. Clay part of the soil and humus forms colloidal particles in the soil. The colloids carry a large number of charges on their surface as well as they have large surface area, for interaction with mineral elements in the soil. The charged surfaces bind large number of ions especially positively charged cations from the soil solution. This is most important property of soil. Soil also has a large number of microorganisms that not only decompose organic remains but also release the minerals bound in organic matter. Nitrogen fixing bacteria increase the usable nitrogen content of soil. Soil is able to maintain a regular supply of minerals partly by the activity of decomposers and partly by slow breakdown and weathering of rocks. This also replenishes the natural slow erosion of the top layers of soil.

However, agriculture is slightly different from natural vegetation. There is more withdrawal of mineral nutrients from soil than their natural replenishment. Therefore, there is often deficiency of essential minerals. Artificial fertilizers are added to remove the same.

NITROGEN NUTRITION OR METABOLISM OF NITROGEN

Nitrogen Cycle (Fig. 12.10). Nitrogen is the fourth most prevalent element in living systems. It is a constituent of a number of organic compounds like amino acids, proteins, nucleotides, nucleic acid, hormones, chlorophyll, many vitamins, etc. However, its availability from soil is limited and even for that plants have to compete with microbes both in natural and agricultural ecosystems. Nitrogen is available in the atmosphere in abundance (78% of atmosphere as dinitrogen or N_2) but plants cannot directly absorb the same. Therefore, nitrogen is the **most critical element**. A regular supply of nitrogen to the plants is maintained through nitrogen cycle. **Nitrogen cycle** is regular circulation of nitrogen amongst living organisms, reservoir pool in the atmosphere and cycling pool in the lithosphere. Nitrogen compounds are obtained from reservoir pool through nitrogen fixation. Reservoir pool is replenished through denitrification of nitrates and release of nitrogen from decaying organic matter. Cycling pool is augmented by ammonification and nitrification. Plants obtain nitrogen from soil as NO_3^- (nitrate), NH_4^+ (ammonium) and NO_2^- (nitrite) ions. Nitrate and nitrite are reduced to ammonium state which is then incorporated into amino acids, proteins and other organic substances.

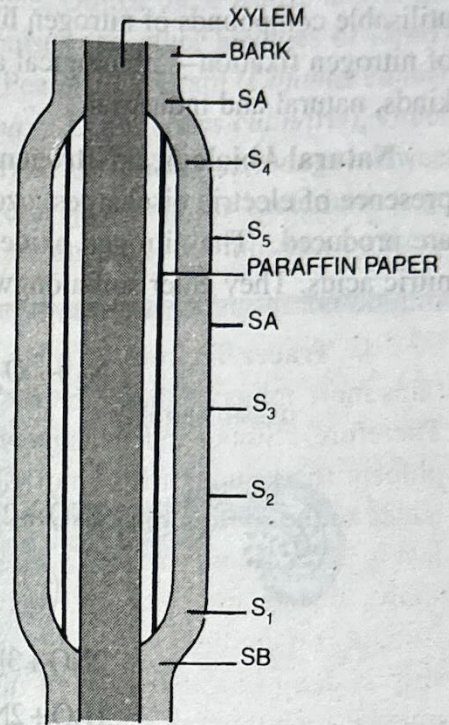


Fig. 12.9. Experiment to show path of mineral translocation as used by Stout and Hoagland (1939).

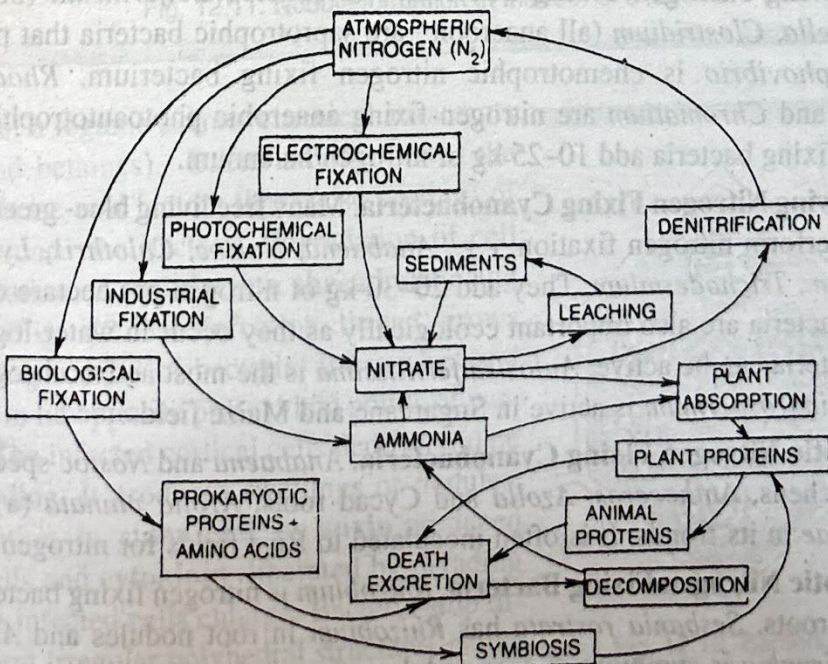
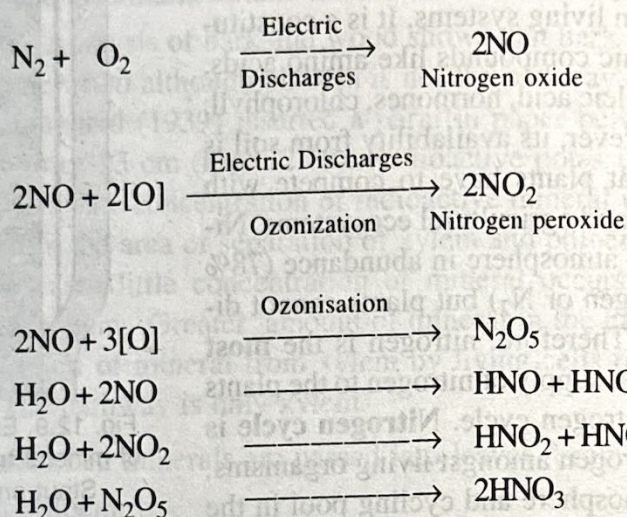


Fig. 12.10. Nitrogen cycle.

Nitrogen Fixation. It is the conversion of inert atmospheric nitrogen or dinitrogen (N_2) into utilisable compounds of nitrogen like nitrate, ammonia, amino acids, etc. There are two methods of nitrogen fixation—abiological and biological. Abiological nitrogen fixation is further of two kinds, natural and industrial.

Natural Abiological Nitrogen Fixation. Atmospheric nitrogen combines with oxygen in the presence of electric discharges, ozonization and combustion. Different types of nitrogen oxides are produced. The nitrogen oxides dissolve in water and give rise to hyponitrous, nitrous and nitric acids. They enter soil along with rain water forming hyponitrites, nitrites and nitrates.



Industrial Abiological Nitrogen Fixation. Ammonia is produced industrially by direct combination of nitrogen with hydrogen (got from water) at high temperature and pressure. It is changed to various types of fertilizers including urea.

Biological Nitrogen Fixation. It is the second most important natural process and the major source of nitrogen fixation which is performed by two types of prokaryotes, bacteria and cyanobacteria (= blue green algae). They include both free living and symbiotic forms.

(a) **Free Living Nitrogen Fixing Bacteria.** *Azotobacter*, *Beijerinckia* (both aerobic) and *Bacillus*, *Klebsiella*, *Clostridium* (all anaerobic) are saprotrophic bacteria that perform nitrogen fixation. *Desulphovibrio* is chemotrophic nitrogen fixing bacterium. *Rhodospseudomonas*, *Rhodospirillum* and *Chromatium* are nitrogen fixing anaerobic photoautotrophic bacteria. Free living nitrogen fixing bacteria add 10–25 kg of nitrogen/ha/annum.

(b) **Free Living Nitrogen Fixing Cyanobacteria.** Many free living blue-green algae (BGA) or cyanobacteria perform nitrogen fixation, e.g., *Anabaena*, *Nostoc*, *Calothrix*, *Lyngbia*, *Aulosira*, *Cylindrospermum*, *Trichodesmium*. They add 20–30 kg of nitrogen per hectare of soil and water bodies. Cyanobacteria are also important ecologically as they occur in water-logged soils where denitrifying bacteria can be active. *Aulosira fertilissima* is the most active nitrogen fixer in Rice fields while *Cylindrospermum* is active in Sugarcane and Maize fields.

(c) **Symbiotic Nitrogen Fixing Cyanobacteria.** *Anabaena* and *Nostoc* species are common symbionts in lichens, *Anthoceros*, *Azolla* and Cycad roots. *Azolla pinnata* (a water fern) has *Anabaena azollae* in its fronds. It is often inoculated to Rice fields for nitrogen fixation.

(d) **Symbiotic Nitrogen Fixing Bacteria.** *Rhizobium* is nitrogen fixing bacterial symbiont of papilionaceous roots. *Sesbania rostrata* has *Rhizobium* in root nodules and *Aerorhizobium* in stem nodules. *Frankia* is symbiont in root nodules of several nonlegume plants like *Casuarina* (Australian Pine), *Myrica* and *Alnus* (Alder). *Xanthomonas* and *Mycobacterium* form symbiotic association with the leaves of several members of rubiaceae and myrsinaceae (e.g., *Ardisia*).

Both *Rhizobium* and *Frankia* live free as aerobes in the soil but are unable to fix nitrogen. They develop the ability to fix nitrogen only as a symbiont when they become anaerobic. *Rhizobium* is rod-shaped bacterium while *Frankia* is an actinomycete. Out of these *Rhizobium* is the most important for crop lands because it is associated with pulses and other legumes of family fabaceae, e.g., Chick Pea or Gram (*Cicer arietinum*), Pigeon Pea or Red Gram (*Cajanus cajan*), Garden or Edible Pea (*Pisum sativum*), Soya bean (*Glycine max*), Lentil (*Lens culinaris*), Green Gram (*Vigna radiata* = *Phaseolus aureus*), Black Gram (*Vigna* or *Phaseolus mungo*), Sweet Clover, Sweet Pea, Alfalfa, Broad Bean, Clover Bean. Several species of the bacterium (e.g., *Rhizobium leguminosarum*, *R. meliloti*) live in the soil. They are unable to fix nitrogen by them-

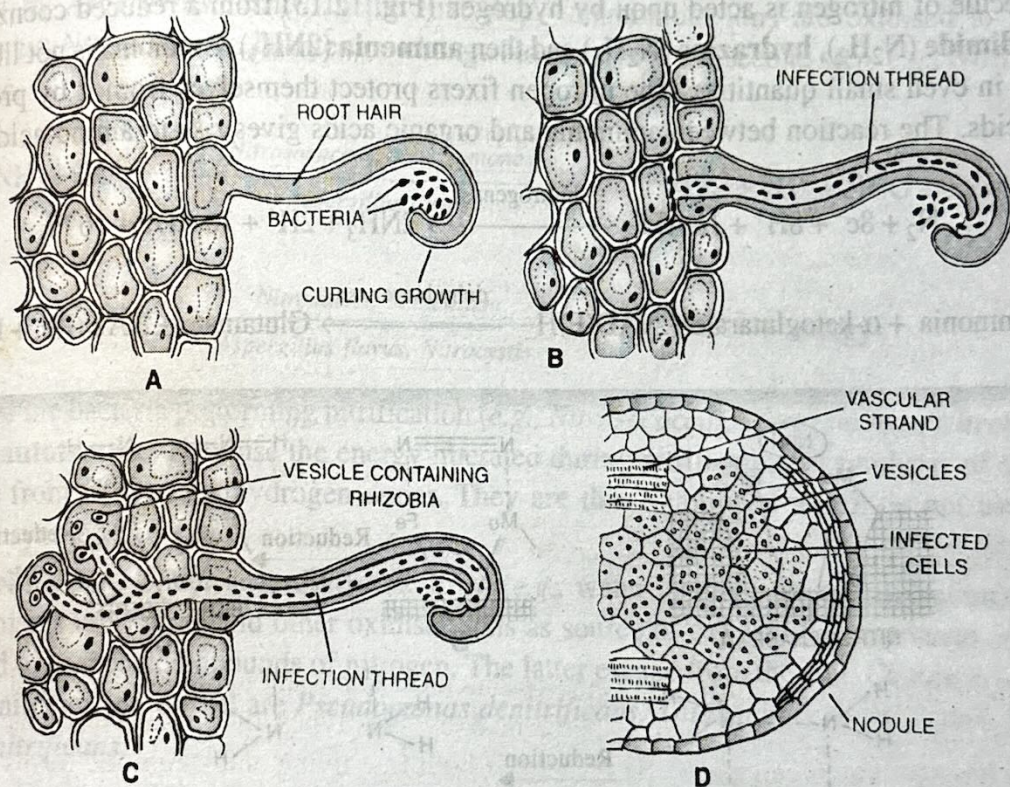


Fig. 12.11. Nodule formation in the root of a legume.

selves. Roots of a legume secrete chemical attractants (flavonoids and betaines). Bacteria collect over the root hairs, release *nod* factors that cause curling of root hairs around the bacteria, degradation of cell wall and formation of an **infection thread** enclosing the bacteria (Fig. 12.11). Infection thread grows along with multiplication of bacteria. It branches and its ends come to lie opposite protoxylem points of vascular strand. The infected cortical cells dedifferentiate and start dividing. It produces swellings or nodules. Nodule formation is stimulated by **auxin** produced by cortical cells and **cytokinin** liberated by invading bacteria. The infected cells enlarge. Bacteria stop dividing and form irregular polyhedral structures called bacterioids (Fig. 12.12). However, some bacteria retain

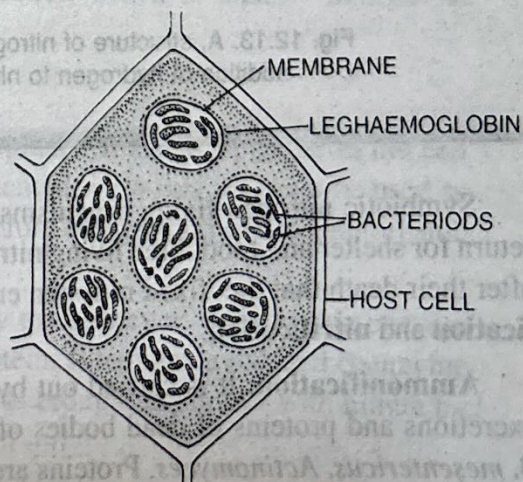


Fig. 12.12. Bacterioids in a nodule.

normal structure, divide and invade new areas. In an infected cell bacterioids occur in groups surrounded by host membrane. The host cell develops a pinkish pigment called **leghaemoglobin (Lb)**. It is oxygen scavenger and is related to blood pigment haemoglobin. It protects nitrogen fixing enzyme nitrogenase from oxygen. Symbiotic nitrogen fixation requires cooperation of *Nod* genes of legume, *nod*, *nif* and *fix* gene clusters of bacteria.

Mechanism of Nitrogen Fixation. Nitrogen fixation requires (i) a reducing power like NADPH, FMNH₂ (ii) a source of energy like ATP (iii) enzyme dinitrogenase and (iv) compounds for trapping ammonia formed by the reduction of dinitrogen. Enzyme nitrogenase has iron and molybdenum. Both of them take part in attachment of a molecule of nitrogen (N₂). Bonds between the two atoms of nitrogen become weakened by their attachment to the metallic components. The weakened molecule of nitrogen is acted upon by hydrogen (Fig. 12.13) from a reduced coenzyme. It produces **dimide** (N₂H₂), **hydrazine** (N₂H₄) and then **ammonia** (2NH₃). Ammonia is not liberated. It is toxic in even small quantities. The nitrogen fixers protect themselves from it by providing organic acids. The reaction between ammonia and organic acids gives rise to amino acids.

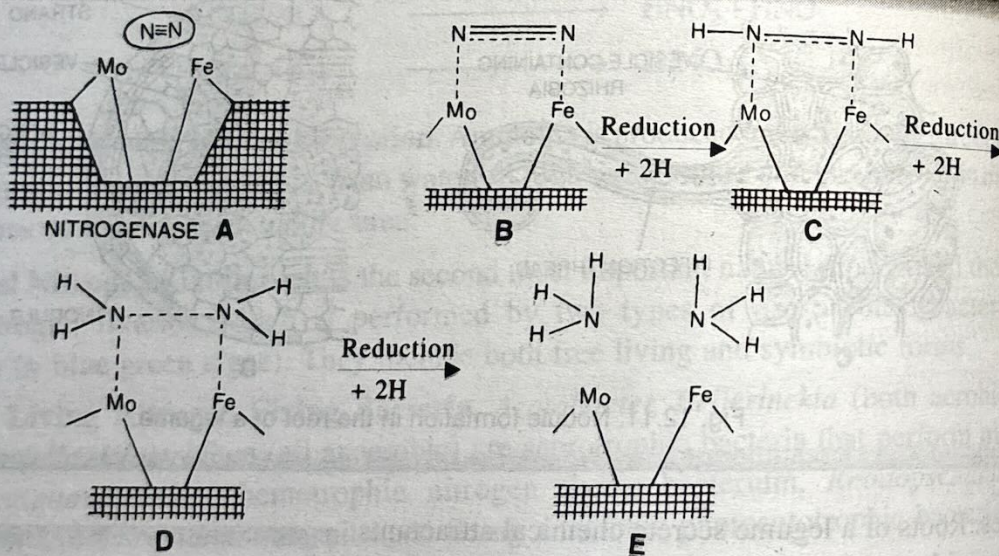
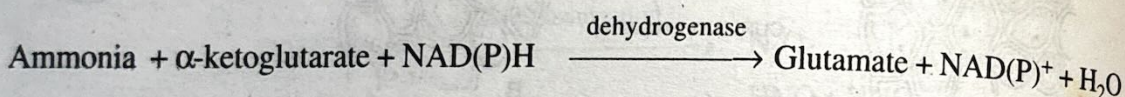
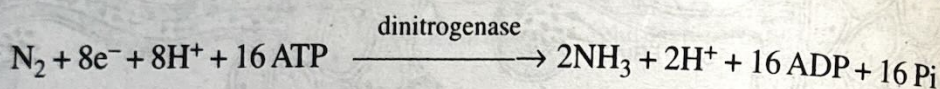
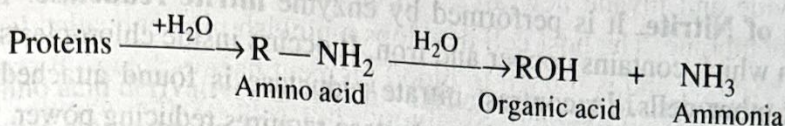


Fig. 12.13. A, structure of nitrogenase; B-E, Weakening of nitrogen bonds and addition of hydrogen to nitrogen with the help of Mo and Fe atoms.

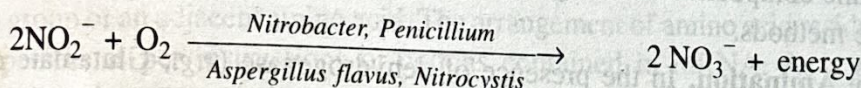
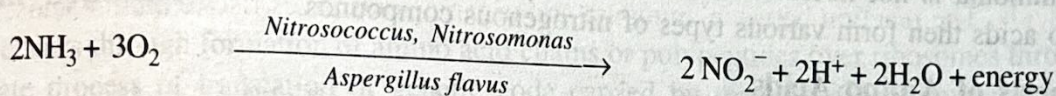
Symbiotic nitrogen fixing organisms hand over a part of their fixed nitrogen to the host in return for shelter and food. Free living nitrogen fixers do not immediately enrich the soil. It is only after their death that the fixed nitrogen enters the cycling pool. It occurs in two steps, **ammonification** and **nitrification**.

Ammonification. It is carried out by decay causing organisms. They act upon nitrogenous excretions and proteins of dead bodies of living organisms, e.g., *Bacillus ramosus*, *B. vulgaris*, *B. mesentericus*, *Actinomyces*. Proteins are first broken up into amino acids. The latter are deaminated. Organic acids released in the process are used by microorganisms for their own metabolism.



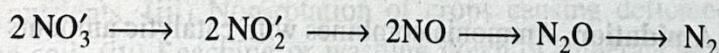
Ammonia does not remain in the gaseous state in the soil but is changed to ionic form (NH_4^+). It can be used by plants directly provided pH of soil is more than 6 and the plant contains abundant organic acids. Unlike nitrates, very few plants can store ammonium ions (e.g., *Begonia*, *Oxalis*).

Nitrification. It is the phenomenon of conversion of ammonium nitrogen to nitrate nitrogen. It is performed in two steps— nitrite formation and nitrate formation. Both the steps can be carried out by *Aspergillus flavus*. In the first step, ammonium ions are oxidised to nitrites *Nitrosococcus*, *Nitrosomonas*. Nitrites are changed to nitrates in the second step, e.g., *Nitrocystis*, *Nitrobacter*.



Most of the bacteria performing nitrification (e.g., *Nitrosococcus*, *Nitrosomonas*, *Nitrobacter*) are **chemoautotrophs**. They use the energy liberated during nitrification in synthesis of organic substances from CO_2 and a hydrogen donor. They are thus autotrophs which do not use solar energy for synthesis of food.

Denitrification. Under anaerobic conditions (e.g., water logging, oxygen depletion), some microorganisms use nitrate and other oxidised ions as source of oxygen. In the process, nitrates are reduced to gaseous compounds of nitrogen. The latter escape from the soil. Common bacteria causing denitrification of soil are *Pseudomonas denitrificans*, *Thiobacillus denitrificans*, *Micrococcus denitrificans*.

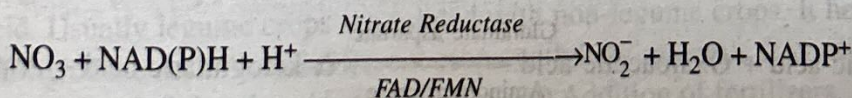


Nitrogen oxides escaping into atmosphere or formed during abiological fixation can also be broken down by raidations to form molecular nitrogen. Denitrification of soil not only depletes the soil of an important nutrient but also causes acidification which is equally harmful in solubilisation of harmful metals.

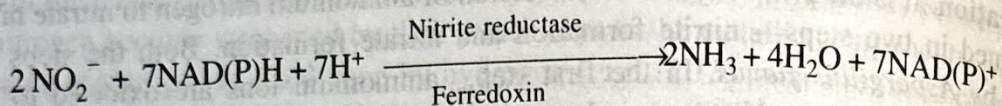
Nitrate Assimilation

Nitrate is the most important source of nitrogen to the plants. It can accumulate in the cell sap of several plants and take part in producing osmotic potential. However it cannot be used as such by the plants. It is first reduced to level of ammonia before being incorporated into organic compounds. Reduction of nitrate occurs in two steps :

(i) **Reduction of Nitrate to Nitrite.** It is carried out by the agency of an inducible enzyme called **nitrate reductase**. The enzyme is a molybdo flavoprotein. It requires a reduced coenzyme (NADH or NADPH) for its activity. The reduced coenzyme is brought in contact with nitrate by FAD or FMN.



(ii) **Reduction of Nitrite.** It is performed by enzyme **nitrite reductase**. The enzyme is a metalloflavoprotein which contains copper and iron. It occurs inside chloroplasts in the leaf cells and leucoplasts of other cells. In contrast nitrate reductase is found attached loosely to cell membrane (Butz and Jackson, 1977). Nitrite reductase requires reducing power. It is NADPH in illuminated cells and NADH in others. The process of reduction also requires **ferredoxin** which occurs in higher plants mostly in green tissues. Therefore, it is presumed that in higher plants either nitrite is translocated to leaf cells or some other electron donor (like FAD) operates in unilluminated cells. The product of nitrite reduction is ammonia.

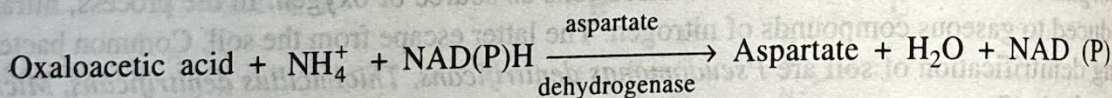
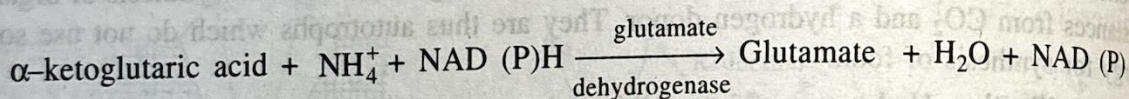


Ammonia is not liberated. It combines with some organic acids to produce amino acids. Amino acids then form various types of nitrogenous compounds.

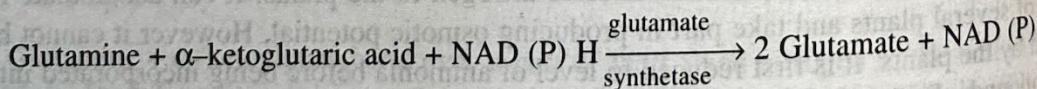
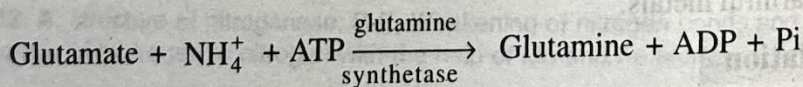
Synthesis of Amino Acids

The first organic compounds of nitrogen assimilation are amino acids. They are synthesised by following three methods.

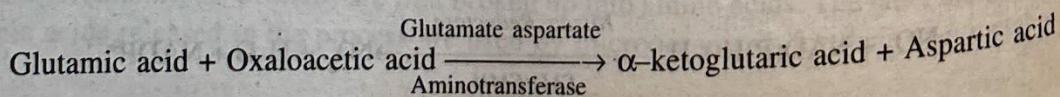
1. **Reductive Amination.** In the presence of dehydrogenase (e.g., Glutamate dehydrogenase, Aspartate dehydrogenase), a reduced coenzyme (NADH or NADPH), ammonia can directly combine with a keto organic acid like α -ketoglutaric acid and oxaloacetic acid to form amino acid.



2. **Catalytic Amidation.** Ammonia combines with catalytic amounts of glutamic acid in the presence of ATP and enzyme glutamine synthetase. It produces an amide called glutamine. Glutamine reacts with α -ketoglutaric acid in the presence of enzyme glutamate synthetase to form two molecules of glutamate. Reduced co-enzyme (NADH or NADPH) is required.



3. **Transamination.** It is transfer of amino group ($>\text{CHNH}_2$) of one amino acid with the keto group ($>\text{C}=\text{O}$) of keto acid. The enzyme required is transaminase or aminotransferase. Glutamic acid is the primary amino acid involved in transfer of amino group (to as many as seventeen amino acids).



Amides

They are amino acid derivatives in which $-OH$ component of carboxylic group ($-COOH$) is replaced by another amino group ($-NH_2$). Amides are, therefore, double aminated keto acids. The two most common amides are glutamine and asparagine. They are formed by amidation of glutamic acid and aspartic acid respectively. Another common amide is vitamin niacinamide (niacin *a*). Glutamine and asparagine are components of proteins along with amino acids. Their formation requires ATP, ammonia and synthetase enzyme (glutamine synthetase, asparagine synthetase). Amides perform two other functions— storage of excess nitrogen and transport. Transport generally occurs via xylem. *Ureides* (degraded urea) are employed as a means of nitrogen transport from the nodules of some legumes (e.g., Soyabean) and retransport from the ageing organs. They have a high nitrogen to carbon ratio.

Protein Synthesis

It occurs through formation of amino acid chains or polypeptides over ribosomes through an elaborate process of translation of genetic code carried by mRNAs. Chain formation occurs through establishment of peptide bonds ($-CONH-$) between carboxylic group of one amino acid and amino group of an adjacent amino acid. The arrangement of amino acid residues in a polypeptide chain is specific as per instructions or codons contained in mRNA. As a result each type of polypeptide has its own specific arrangement. Polypeptides give rise to proteins. Therefore, proteins are also highly specific.

Mineral Fertility

Soil fertility is the ability of a soil to support luxuriant plant growth. It is determined by mineral nutrients, soil air, soil water and absence of plant pathogens. Soil air and soil water can be restored through proper ploughing and irrigation. Plant pathogens are killed naturally by crop rotation, pesticides and fungicides.

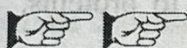
Minerals get depleted in the soil due to several reasons : (i) Overcropping which withdraws minerals from the top layers of the soil. (ii) Use of high yielding varieties which require higher quantity of mineral nutrients. (iii) Non-rotation of crops causing deficiency of minerals at a particular level in the soil. (iv) Leaching or washing down of minerals along with gravitational water. (v) Pre-cipitation of minerals due to change in soil pH.

Restoration of Mineral Fertility. It is done through two methods, natural and artificial.

(a) **Natural Replenishment.** In soil under natural vegetation, mineral fertility is restored naturally through (i) Recovery of minerals from decomposition of fallen leaves, twigs, dead roots, dead animals and animal excreta. (ii) Slow process of weathering of bed rocks. (iii) Burrowing habit of some animals like earthworms which bring subsoil over the surface of top soil. (iv) Biological nitrogen fixation. (v) Passing down of nitrogen, sulphur and other salts from atmosphere to soil through rain. (b) **Artificial Replenishment.** It is carried out by human efforts. (i) Addition of farmyard manure. Manure contains **humus** or dark brown amorphous substance formed by degradation of cellulose and lignin. Humus forms colloidal particles in soil for increased hydration, crumb structure, aeration, loosening the soil, slow release of minerals and organic substances that stimulate plant growth. (ii) Green manuring. Here a young green leguminous crop (like clover, guar, sunn hemp) is ploughed back into the soil for providing humus, decreasing soil alkalinity and increasing nitrogen supply. (iii) Crop rotation or sowing of alternate crops successively in the same field. Usually legume crops are rotated with non-legume crops. It helps in maintaining nitrogen fertility of the soil. As the different crops withdraw minerals from different depths, the soil does not become deficient in minerals rapidly. (iv) Addition of fertilizers.

Fertilizers. They are compounds or mixture of chemicals which are added to the soils in order to overcome deficiency of minerals. The most common mineral elements which become deficient in agricultural soils are nitrogen, phosphorus and potassium (NPK). They are called **critical elements**. Majority of the fertilizers, therefore, contain all the three critical elements. Such fertilizers are called **complete fertilizers**. Common fertilizers consist of chemicals, either singly (simple or straight fertilizer) or in various combinations (compound or multinutrient fertilizer), like urea, nitrate of soda, ammonium sulphate, ammonium nitrate, ammonium chloride, calcium ammonium nitrate, superphosphate, calcium magnesium phosphate, rock phosphate, bone meal, etc. Ammonium is a better source of nitrogen for areas with high rate of leaching and photosynthesis. The common complete or NPK fertilizers contain nitrophosphate with potash. The percentage of nitrogen, phosphorus and potassium by weight is mentioned, such as 15-15-15, 17-18-19, etc. The amount and type of fertilizers to be added to the soil depends upon the soil conditions, crop, season, rainfall and climatic conditions.

Microelements are added to fertilizers in small quantities. However, utility of micronutrient depends upon the deficiency in soil and pH of the soil. For example, in alkaline soil Cu, Zn, Mn and Fe become easily precipitated. It is preferable that deficient microelements and costlier macronutrients be sprayed over the plants. The practice is called foliar nutrition or foliar fertilizers.



ADDITIONAL INFORMATION



- **Liebig.** Father of Biochemistry who recorded minerals in plant ash and proposed the law of minimum.
- **Gericke.** Developed hydroponics.
- **Aeroponics.** It is the technique of growing plants in above-ground strands provided with fine mist of normal solution.
- **Neher and Sakmann.** Got Nobel prize for discovering single ion channels in the plasma membrane.
- **Most Free Ion.** Potassium.
- **Primary Deficiency.** Deficiency caused by a critical element (N, P or K).
- **Winogradsky (1891).** Discovered biological nitrogen fixation.

NCERT TEXTBOOK QUESTIONS WITH ANSWERS

1. All elements that are present in a plant need not be essential to its survival. Comment.
 ✓ Almost all elements which are present in soil and which get solubilised enter the plants. Nearly 60 elements have been detected in plants. However, all of them are not essential. Many of them simply enter the plants because of the common pathway with the essential elements, e.g., lead, gold, selenium.
2. Why is purification of water and nutrient salts so important in studies involving mineral nutrition using hydroponics.
 ✓ Some minerals are required in extremely small quantity of even less than 1 µg /g of dry matter. Such small quantities are often present in water as well as in commercially available salts. Therefore, exact physiological role and deficiency symptoms of some elements cannot be studied unless and until extra pure water and extra pure salts are not used in studies employing hydroponics.
3. Explain with examples : (i) Macronutrients, (ii) Micronutrients, (iii) Beneficial nutrients, (iv) Toxic elements, (v) Essential elements.
 ✓ **Macronutrients.** They are those essential elements which occur in easily detectable quantities of 1–10 mg/g of dry matter, e.g., C, H, O, N, P, K, S, Mg, Ca.
Micronutrients. Micronutrients are essential elements found in plants in small quantities of 0.1 mg or less/g of dry matter, e.g., Fe, Zn, Mn, B, Cu, Mo, Cl, Ni.
Beneficial Nutrients. Nonessential elements which are required in metabolic activities of some plants are called **nonessential functional** or **beneficial elements**, e.g., silicon in grasses, cobalt, vanadium, sodium.

Toxic Elements. The elements which when present reduce growth of plants by 10% or more are known as toxic elements, e.g., Lead, Aluminium. Most micronutrient also become toxic in higher concentration, e.g., Mn^{2+} .

Essential Elements. They are elements which have specific structural or functional roles in plants and without which plants are unable to complete their life cycle. Their deficiency produces disorders which can be corrected only by their supply, e.g., C, H, O, N, P, K, S, Mg, Ca, Fe, Zn, Mn, etc.

4. Name atleast five different deficiency symptoms in plants. Describe them and correlate them with the concerned mineral deficiency.

✓ (i) **Interveinal Chlorosis.** Appearing first in young leaves, veins initially green _____ Iron.

(ii) **Scorched Leaf Tips.** Potassium.

(iii) **Whiptail Disease.** Molybdenum.

(iv) **Exanthema** (skin splitting and exudation of gummy matter). Copper.

(v) **Death of both Root and Shoot Tips.** Boron (also disintegration of softer regions).

5. If a plant shows a symptom which could be due to deficiency of more than one nutrient, how would you find out experimentally the real deficient mineral element ?

✓ Dilute solutions of all the possible deficient nutrients are prepared. A number of plants are grown in small pots using the nutrients deficient soil. Dilute solutions of different nutrients are added in different pots. In one set the growth of plants will become normal. The nutrient supplied to these plants had been deficient.

6. Why is that in certain plants deficiency symptoms appear first in younger parts of the plant while in others they do so in mature organs ?

✓ Deficiency symptoms appear first in the young parts for elements which are relatively immobile inside the plant, e.g., Ca, S. They appear first in mature organs for those elements which are mobilised from senescing regions for supply to younger regions, e.g., N, P, K, Ni.

7. How are the mineral elements absorbed by the plants ?

✓ Minerals are absorbed by cells of the root apex, zone of elongation and root hairs. Minerals absorbed by root hair zone are meant for passage to shoot while the ones absorbed by root apex and zone of elongation remain in the root.

Mineral absorption is an **active process**. It has two phases, initial phase and metabolic phase. Initial phase is a passive process where in ions absorbed from outside pass in outer or free space of the cells. It comprises intercellular spaces and cell walls. The **metabolic phase** is an active process wherein ions enter the cytoplasm and cell vacuole. Entry of ions into cells is called **influx**.

8. What are the conditions necessary for fixation of atmospheric nitrogen by *Rhizobium* ? What is their role in N_2 fixation.

✓ **Conditions.** (i) Reducing environment. (ii) Presence of enzyme nitrogenase. (iii) Source of energy as ATP. (iv) Source of reducing power, NAD (P) H_2 or FMNH₂. (v) Ferredoxin as electron donor. (vi) Ketoacids for picking up amino group. (vii) Reduced availability of nitrate in the substrate.

Role. (i) Enzyme nitrogenase is sensitive to presence of free oxygen. Therefore, a reducing environment is required. (ii) Enzyme nitrogenase helps in converting dinitrogen (N_2) to ammonia (NH_3). (iii) Reducing power or hydrogen is provided by NAD (P) H_2 or FADH₂. (iv) Ferredoxin makes nitrogen reactive. (v) Organic acids are required for formation of amino acids. (vi) Nitrate inhibits nitrogen fixation. Therefore, nitrate deficiency is prerequisite for nitrogen fixation.

9. What are the steps involved in formation of a root nodule ?

✓ Legume roots secrete flavonoids and betaines. They attract rhizobia. The bacteria collect over the root hairs and release *nod* factors. *Nod* factors cause curling of root hairs around the bacteria. Root hair wall degrades in the region. An infection thread containing the bacteria grows into root hair and then into the interior of root. Bacteria multiply in the infection thread. The infection thread branches. The branches reach and enter cortical cells opposite the protoxylem points. The infected cells dedifferentiate and start dividing. The stimulus is provided by auxin formed by cortical cells and cytokinin liberated by bacteria. The cells enlarge. A nodule is formed. In the infected cells of the nodule, the bacteria stop dividing and form polyhedral structures called **bacterioids**. Groups of bacterioids get surrounded by host membrane. In legume roots, a pinkish pigment called **leghaemoglobin** is formed over the bacterial mass.

10. Which of the following statements are true ? If false, correct them.

(a) Boron deficiency leads to stout axis.

(b) Every mineral element that is present in a cell is needed by the cell.

(c) Nitrogen as a nutrient element, is highly immobile in the plants.

(d) It is very easy to establish the essentiality of micronutrients because they are required only in trace quantities.

✓ (a) True

(b) False. Only some elements called essential elements are required.

(c) False. It is mobile.

(d) False. Micronutrients being trace elements are difficult to diagnose. They are often present as contaminants in materials of containers, water, cotyledons and along with macronutrients.

TEST QUESTIONS

One Mark Questions (With Answers)

1. Name the enzyme involved in biological nitrogen fixation.

✓ Nitrogenase.

2. What is nitrification ?

✓ It is the phenomenon of conversion of ammonium nitrogen to nitrate nitrogen.

3. Which pigment is present in the root nodules of legumes ?

✓ Leghaemoglobin.

4. Name the best known symbiotic nitrogen fixing bacterium.

✓ *Rhizobium*.

5. What type of condition is created by leghaemoglobin in the root nodule of a legume ?

✓ Anaerobic

6. How was it proved that minerals pass through xylem and not phloem ?

✓ By tracer technique (Stout and Hoagland, 1939)

7. What is primary deficiency ?

✓ Deficiency which is caused by critical elements (N.P.K.)

8. Which is the most abundant element in plant body ?

✓ Oxygen

9. What are framework elements ?

✓ Elements involved in the synthesis of cell wall and storage materials viz. C, H, O.

10. Name the scientist who introduced hydroponics.

✓ Gericke (1940)

11. Pick out from the following list the two minerals which are not needed by the majority of plants but very much needed by almost all animals: Calcium, sodium, potassium, iron, iodine.

✓ Sodium, Iodine.

12. Match the words in Column I with phrases in Column II

Column I

(a) Magnesium

(b) Sulphur

(c) Calcium

(d) Iodine

(e) Manganese

Column II

(i) found in middle lamella

(ii) a structural component of chlorophyll

(iii) required for enzyme activity

(iv) found in some amino acids

(v) a component of sugars

(vi) not important for plants.

✓ (a)—(ii), (b)—(iv), (c)—(i), (d)—(vi), (e)—(iii)

One Mark Questions (Without Answers)

13. Name the pigments found in the root nodules of the leguminous plant.

14. How does leghaemoglobin protect the nitrogenase ?

15. Define the terms : (i) Hydroponics (ii) Micronutrients (iii) Macroelements (iv) Carnivorous plants (v) Nutrient.

16. Name the best known symbiotic nitrogen fixing bacterium.

17. Which are two micronutrients that play role in limiting plant growth usually ?

18. What is leghaemoglobin ?

19. Define biological nitrogen fixation.

20. What is conductive tissue for mineral nutrients in plants ?

Two Mark Questions (With Sample Answers)

21. List the macronutrients and mention their major function.

✓ C, H, O, N, P, K, S, Mg, Ca, Fe. These are involved in synthesis of organic molecules and development of osmotic potential.

22. What are the two macronutrients that usually play the most important role in limiting plant growth locally.

✓ Macronutrients which often become limiting in plant growth are called **critical elements**. They are three in number (N, P, K). Two of them are nitrogen and phosphorus. Their availability in soil is generally lower than the amount required by plants.

☉ Two Mark Questions (Without Answers)

23. Name a chelate. Why is iron added in hydroponics along with chelating agent ?
24. Why do farmers use leguminous crops to provide nitrogen to the soil ? Explain.
25. Prior to sowing rice, a legume crop was cultivated and ploughed back in the field, why ? Explain.
26. Name the organism that fixes nitrogen in symbiotic association with a water fern. Where does it live in such plants.
27. A farmer adds *Azotobacter* culture to the soil before sowing maize. How does it increase the yield of maize ?
28. Describe an experiment that was used to prove that xylem translocates minerals.
29. What is hydroponics ? Give one application of this technique.
30. Name the respective mineral nutrient element that (i) forms the core constituent of the ring structure of chlorophyll (ii) activates carboxylases (iii) forms the component of nitrogenase (iv) synthesises middle lamella of plant cells.

☉ Three Mark Questions (Short Answer Type)

31. Differentiate between macroelements and microelements.
32. What is 'dieback' ? Name the element which results in this malformation in its deficiency.
33. Why do plants need Potassium and Magnesium ?
34. If you grow a potted plant that initially weighed 200g and eventually weighed 50kg would you expect the soil in the pot to change weight ? Explain.
35. What are various steps involved in the biological nitrogen fixation in plants ?
36. What are the criteria for an element to be considered as essential part of life ?
37. Differentiate between essential and nonessential mineral elements.
38. Name the nitrifying bacteria of the soil. Why are they called chemoautotrophs ?
39. Why do farmers use leguminous crops to provide nitrogen to the soil ? Explain.
40. Describe the mechanism of mineral absorption by ion-exchange method.
41. What is importance of minerals in plant life.

☉ Five Mark Questions (Long Answer Type)

42. What are fertilizers ? Why are they needed ? What do you mean by NPK fertilizers ?
43. What are the indications for mineral deficiency in plants.
44. Differentiate between two types of absorption of minerals from soil through roots.
45. Explain symbiotic nitrogen fixation.
46. Describe two important functions each of K, Fe and Zn in green plants and also write deficiency symptoms of any two of them.
47. Make a table showing macroelements, region of plants in which required, functions and their deficiency symptoms.

☉ Multiple Choice Questions (With Answers)

- (1) In plants nitrate is reduced to ammonia state in two steps. In second step, electrons are donated by (a) Ferredoxin (b) Nitrate reductase (c) Nitrite reductase (d) Cytochrome b_5 (e) Cytochrome P_{450}
- (2) Element present in middle lamella (a) Zn (b) Ca (c) Cu (d) K.
- (3) Salt respiration is (a) Increase in respiration during mineral absorption (b) Decrease in respiration during salt absorption (c) Linking ion movement with respiratory chain (d) Secretion of salt through respiratory channels.
- (4) Nonsymbiotic nitrogen fixing prokaryote is (a) *Frankia* (b) *Azotobacter* (c) *Rhizobium* (d) *Acetobacter*.
- (5) Hydroponics refers to growing plants in (a) Tissue culture medium (b) Water (c) Solution of mineral nutrients (d) Soil culture. (AFMC 2003)
- (6) Main role of minor elements is to act as (a) constituent of hormones (b) Binder of cell structure (c) Cofactor of enzymes (d) Constituent of amino acids. (CBSE 2003)
- (7) Plants with zinc deficiency show reduced bioynthesis of (a) Ethylene (b) Absciscic acid (c) Cytokinin (d) Auxin. (CBSE 2003)

- (8) Grey spots of Oat are due to deficiency of (a) Fe (b) Zn (c) Cu (d) Mn
- (9) The most abundant element found in plants is (a) Carbon (b) Nitrogen (c) Iron (d) Manganese. (CBSE 2003)
- (10) Element required for biological nitrogen fixation is (a) Zinc (b) Molybdenum (c) Copper (d) Manganese. (CBSE 2004)
- (11) Copper is activator in enzyme (a) Carbonic anhydrase (b) Tyrosinase (c) Lactic dehydrogenase (d) Manganese. (AIEEE 2004)
- (12) Macronutrient which is component of all organic compounds but is not obtained from soil is (a) Nitrogen (b) Phosphorus (c) Magnesium (d) Carbon. (CBSE 2004)
- (13) Which group of three micronutrient elements is required for both photosynthetic and mitochondrial electron transport (a) Cu, Mn, Fe. (b) Co, Ni, Mo. (c) Ca, K, Na. (d) Mn, Co, Ca. (KCET 2005)
- (14) Sulphur is important nutrient for optimum growth and productivity of (a) cereals (b) oil crops (c) pulse crops (d) fibre crops. (CBSE 2005)
- (15) Function of leghaemoglobin during biological nitrogen fixation in root nodules of legumes is to (a) convert N_2 to NH_3 (b) convert ammonia to nitrite (c) transport oxygen for nitrogenase activity (d) protect nitrogenase from oxygen. (CBSE 2006)
- (16) Component of nitrogenase and nitrate reductase is (a) Mn (b) Mo (c) Co (d) Zn. (AIIMS 2006)
- (17) Element required for germination of pollen grain is (a) Chlorine (b) Boron (c) Calcium (d) Potassium. (Orissa 2006)
- (18) Magnesium is component of (a) chlorophyll (b) enzymes (c) florigen (d) haemoglobin. (Gujarat 2007)
- (19) Nitrification involves (a) NH_3 (b) NO_2^- (c) NO_3^- (4) All the above. (CBSE 2007)
- (20) An immobile element in plants is (a) Calcium (b) Potassium (c) Nitrogen (d) Phosphorus. (DPMT 2008)
- (21) Manganese is required for (a) Chlorophyll synthesis (b) Plant cell wall formation (c) Photolysis of water in photosynthesis (d) Nucleic acid synthesis. (AMU 2009)
- (22) Denitrification is carried out by (a) *Nitrosomonas* (b) *Nitrosococcus* (c) *Nitrobacter* (d) *Pseudomonas*. (CBSE 2009)
- (23) An element playing important role in nitrogen fixation is (a) copper (b) manganese (c) zinc (d) molybdenum. (AMU 2010, MP PMT 2010)
- (24) Denitrification is carried out by (a) *Pseudomonas* and *Nitrococcus* (b) *Nitrosomonas* and *Nitrobacter* (c) *Nitrosomonas* and *Nitrococcus* (d) *Pseudomonas* and *Thiobacillus*. (CBSE 2010)
- (25) Which helps in absorption of phosphorus from soil by plants ? (a) *Glomus* (b) *Frankia* (c) *Anabaena* (d) *Rhizobium*. (HPPMT 2011)
- (26) Which helps in absorption of phosphorus from soil by plants ? (a) *Glomus* (b) *Frankia* (c) *Anabaena* (d) *Rhizobium*. (CBSE 2011)

Assertion and Reason Type Questions

In each of the following questions two statements are given, one is Assertion (A) and other is Reason (R). For the (A) and (R) statements, mark the correct answer as—

- (A) If both A and R are true and R is the correct explanation of A
 (B) If both A and R are true and R is not the correct explanation of A
 (C) If A is true but R is false. (D) If both A and R are false.

1. **Assertion.** Stomata open and close in response to turgor changes.

Reason. pH changes are brought about by influx and efflux of H^+ ions.

- (A) (B) (C) (D)

2. **Assertion.** Deficiency of sulphur causes chlorosis in plants.

Reason. Sulphur is constituent of chlorophyll, proteins and nucleic acid.

- (A) (B) (C) (D)

3. **Assertion.** Nitrogen fixing bacteria of legume nodules survive in oxygen depleted cells.

Reason. Leghaemoglobin completely removes oxygen from nodule cells.

ANSWERS

Multiple Choice Questions (With Answers)

- (1) —a (2) —c (3) —a (4) —b (5) —c (6) —c (7) —d (8) —d (9) —a (10) —b
 (11) —b (12) —d (13) —a (14) —c (15) —d (16) —b (17) —b (18) —d (19) —d (20) —a
 (21) —c (22) —d (23) —d (24) —d (25) —a

Assertion and Reason Type Questions

- (1) —C (2) —C (3) —C